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EFFECTS OF GROWTH STAGE, WEATHER FACTORS AND ADJUVANTS ON HERBICIDE ACTIVITY AGAINST THE STERILE BROME - AN AID TO DEFINING 'WEATHER WINDOWS' FOR SPRAYING

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EFFECTS OF GROWTH STAGE, WEATHER FACTORS AND ADJUVANTS ON HERBICIDE ACTIVITY AGAINST STERILE BROME – AN AID TO DEFINING WEATHER WINDOWS FOR SPRAYING

by

J. C. CASELEY, P. GENDLE, V. DOWN AND H. BAGGETT

Long Ashton Research Station, Institute of Arable Crops Research,

Department of Agricultural Sciences, University of Bristol,

Long Ashton, Bristol BS18 9AF

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ABSTRACT

The aims of this project were to quantify the importance of weather factors before and after spraying on the activity of herbicides used to control sterile brome, to define 'weather windows' for optimum herbicide activity and to improve herbicide performance under adverse conditions by the use of adjuvants.

Sterile brome was planted in sandy clay loam soil contained in 10 cm diameter pots and grown in defined environments where one factor was varied while the others were held constant so that the importance of individual factors could be identified. In outside and glasshouse situations the microclimate was closely monitored. Extensive use was made of controlled environment enclosures and a rain simulator.

The herbicides were most effective when applied early post-emergence of the weed and although reduced, activity was still acceptable at the 4 leaf growth stage. Recommended field doses of chlorotoluron, isoproturon and metoxuron failed to control plants with 6 leaves and 3 tillers; only SMY1500 and, to a lesser extent, cyanazine were phytotoxic at this growth stage. Chlorotoluron, isoproturon and metoxuron performed best when post-spraying temperatures were cool (10/4°C day/night respectively and lower) and when 3 or 6 mm of simulated rain was applied after spraying. Activity of these herbicides was reduced under warmer conditions (15/10°C day/night respectively and higher) while SMY1500 and cyanazine performed well at higher temperatures.

Pre-emergence application of cyanazine and isoproturon to a 'dry' compared to moist soil surface (1 cm at 35 ± 10% compared to 85 ± 10% field capacity) reduced activity whether post-spraying rain was applied or not. In contrast, tri-allate was unaffected by surface soil moisture.

Post-emergence application of cyanazine and isoproturon to brome grown in dry soil (35% field capacity, FC) had little effect when low FC was maintained. However, watering the plants from above and increasing the soil moisture to 100% FC resulted in high herbicide activity due to movement of herbicide down the soil profile and rapid development of adventitious roots into this herbicide containing zone.

Adjuvants including Agral and Silwet L-77 significantly enhanced the activity of post-emergence herbicide treatments against brome, but the risk of crop damage was also increased.

Frost and relative humidity had little effect on herbicide activity.

OBJECTIVES

1. To identify and quantify the weather and plant factors that influence herbicide performance against sterile brome, and thus provide the basis for more precise field recommendations for the control of this weed.
2. Evaluate adjuvants for improving control of sterile brome under adverse conditions.

INTRODUCTION

Barren brome (*Bromus sterilis*) has become an increasingly widespread weed of winter cereals, particularly those established by reduced cultivation systems (Froud-Williams *et al.* 1980) where straw burning had been reduced (Rule 1989). The most recent brome grass survey revealed a continuing increase in the incidence and severity of brome grass infestations (Cussans 1991) with 42% of surveyed fields affected. The ban on straw burning and the introduction of set-aside are further increasing the problem (Clarke 1991).

A major factor contributing to the increased status of this weed is that its control with herbicides is often poor (Pollard & Richardson 1981, West 1990) with inconsistent herbicide activity from site to site and with considerable seasonal variability (Orson 1981, Rule 1989). These results indicate that soil and weather conditions play key roles in determining herbicide activity against brome and the aim of this project is to identify and quantify these factors to provide the basis for more precise field recommendations. When weather windows for optimum control are not available, knowledge of the effects of adverse conditions will assist in the choice of adjuvants.

Most of the herbicides in this programme were older compounds such as tri-allate and isoproturon as recently introduced graminicides for use in cereals do not control brome grasses. One 'compound still under development' with activity against brome was included.

MATERIALS AND METHODS

Facilities

In order to rank the importance of individual environmental factors in relation to their effect on herbicide performance, it was necessary to use facilities where one factor can be varied while others are held constant (Caseley 1987). Consequently, extensive use was made of the Long Ashton controlled environment facility and precision rain simulator, while in glasshouse and outside locations the micro-climate was monitored to facilitate interpretation of the results.

Plants and soil

Long Ashton stock bed sterile brome seed was planted at a depth of 1 cm in sandy clay loam soil contained in 10 cm diameter pots. Four seeds were sown and thinned to three plants after seedling emergence. Immediately after sowing the pots were watered once from above and thereafter the soil was maintained close to field capacity by sub-irrigation. Plants grown outside were transferred to a plastic tunnel when rain was forecast and all post-spraying rain treatments were made with the rain simulator.

Herbicide treatments

In most experiments the herbicides were applied at 80, 60, 40 and 20% of their recommended field doses with a laboratory pot sprayer fitted with a Spray Systems 8001 nozzle. The pressure was 207 KPa and the carriage speed was set to deliver 200 L ha^{-1}. The figures and tables indicate where other doses were used.

Herbicide recommended field doses

Herbicide	Dose kg/ha^{-1}
Chlorotoluron	3.0
Cyanazine	2.0
Isoproturon	2.4
Metoxuron	3.0
SMY1500*	2.0
Tri-allate	2.0

Experimental design and assessments

A randomised block design was used with 4 replicate pots for herbicide treatments and 8 replicates for untreated controls. The shoot fresh and dry weight data were subjected to an analysis of variance.

A visual assessment (0 dead; 7 as untreated control) was made 2-3 weeks after spraying. Foliage fresh and dry weights were recorded when regrowth had developed on sub-lethal treatments. This ranged from 4-10 weeks after spraying depending on growth stage at treatment and post-spraying temperature regime.

Effects on herbicide activity of growth stage, temperature and rain

The herbicides were applied pre-emergence and to plants with 2, 4 and 6 leaves on the main shoot. Prior to spraying, the plants were grown outside or in a controlled environment set at 10/4 °C and 77/90%RH day/night respectively where the light regime was 197 W/m^2 for 14 h. Following herbicide application sets of plants were grown:

1) in a controlled environment at 10/4, 14/7 or 16/10 °C
2) outside with and/or without a polythene tunnel rain cover
3) in a glasshouse at 15/10 ± 5 °C.

* SMY1500 has been withdrawn by the manufacturers.

One week after spraying sets of plants were subjected to 0, 3 and 6 mm of rain. Other environmental conditions are given in the figures and tables.

Effect of soil moisture

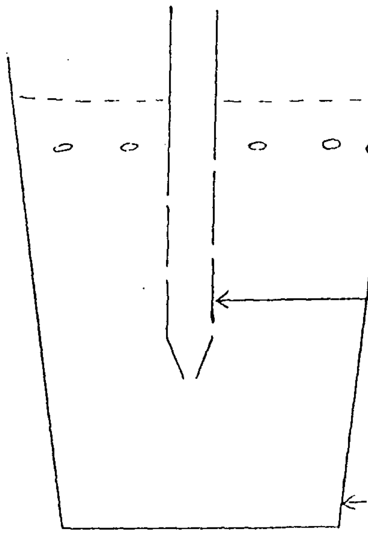
1) **Effect on herbicide activity of the moisture content of the soil surface and post-spraying rain**

Ten cm diameter pots were filled to within 2 cm of the rim with sandy clay loam soil close to field capacity (FC). Four *B. sterilis* seeds were placed on the soil surface and immediately before herbicide application, they were covered with 1 cm of soil at 35±10 or 85±10% FC to provide 'dry' and 'wet' surfaces respectively. Thereafter the soil was kept close to FC by sub-irrigation via aluminium foil dishes. Rain at 3 and 6 mm/h was applied with the Long Ashton precision rain simulator seven days after herbicide treatment. Cyanazine and isoproturon were applied as described earlier. Tri-allate granules were weighed for each pot to provide a dose of 1.28 kg AI/ha and applied from a small vial with a perforated cap. Following herbicide application the pots were transferred to a controlled environment room set at 10/4°C and 77/90% RH day/night respectively.

2) **Effect of water deficit stress on the activity of cyanazine and isoproturon.**

Water was added to air dried soil to give a moisture content of 25% FC and weighed into polystyrene cups. A 5 ml plastic pipette tip with four 3 mm holes in the lower 50 mm was inserted in the soil so that water could be added by syringe to the mid zone of the soil profile. Water requirement was determined by weighing the cups twice weekly and the cups were maintained at 25 or 100% FC. The plants were grown in a controlled environment at 16/10±1°C.

System for controlled soil moisture study.



Effect on herbicide activity of spraying the foliage only, the soil only, or both and with watering from above or below

Plants were sprayed at the 2-3 leaf growth stage and for foliage only treatments the soil was covered with plastic beads which were removed after spraying. The soil only treatments were applied by syringe as a soil drench (10 ml per pot). A rose sprinkler attached to a hose pipe was used for watering from above and sub-irrigation was via aluminium foil dishes; watering by both methods kept the soil close to field capacity. Throughout the experiment plants were kept in a glasshouse with average day/night temperatures of 15/10°C respectively.

Effect on herbicide activity of frost and humidity

The frost and contrast in humidity regimes were imposed in controlled environment cabinets as detailed in the tables.

Effect on herbicide activity of adjuvants

The adjuvants used were the widely used non-ionic surfactant, Agral, the organo-silicone surfactant Silwet L-77, the vegetable oil adjuvant Codacide, the synthetic polymer adjuvant Vinamul 18181 and the synergist tridiphane. All these were added to the herbicide spraying solutions as tank mixes at the concentrations shown in the tables and figures.

RESULTS

Effect on herbicide activity of growth stage of sterile brome

All of the herbicides applied at the 2-leaf growth stage provided good control of sterile brome when the plants were kept in cool conditions and subjected to post-spraying rain (Table 1). SMY 1500 was the most active herbicide with chlorotoluron significantly less effective. At the 4-leaf growth stage activity for all the herbicides tended to be less, but was still acceptable, with SMY 1500, cyanazine and isoproturon being the most active. The columns in Figure 1 represent the average fresh weight of plants kept at high and low temperatures and with and without post-spraying rain. Cyanazine and SMY1500 performed well at all three growth stages while chlorotoluron, isoproturon and metoxuron were ineffective at the 6-leaf growth stage.

All of the herbicides were least effective when applied at the 6-leaf 3-tiller growth stage, but cyanazine and SMY1500 gave acceptable control.

Pre-emergence treatments at 80% of the recommended field dose were equivalent in performance to post-emergence applications at the 4-leaf growth stage for isoproturon and SMY1500 and the 6-leaf growth stage for cyanazine.

Effect on herbicide activity of temperature, frost and humidity

All of the herbicides performed relatively well under cool conditions (Tables 2 and 3), but when the temperature was warm throughout or during the post-spraying period the performance of chlorotoluron, isoproturon and metoxuron declined (Table 3). Cyanazine and SMY1500 tended to be more active in warmer environments. The results in Table 4 show that frost (-2 or -6 °C) had no significant effect on the activity of the herbicides against brome grass and neither did humidity (Table 7).

Effect on herbicide activity of soil surface moisture content at time of spraying and post-spraying rain

Figure 3 shows the pre-emergence activity against barren brome of cyanazine, isoproturon and tri-allate applied to 'wet' and 'dry' soil surfaces. Without rain there was little isoproturon activity with either moisture regime. Cyanazine was slightly more effective, but only tri-allate provided useful control when applied to 'dry' soil.

Following either 3 or 6 mm of rain seven days after spraying, both cyanazine and isoproturon controlled sterile brome when the herbicides were applied to 'wet', but not 'dry' soil. Cyanazine tended to perform better than isoproturon following application to the 'dry' soil but the plants survived. Tri-allate killed or severely stunted growth with the highest activity following 6 mm of rain, but for this herbicide there was no significant difference between any of the moisture and rain regimes.

Effect on herbicide activity of drought stress on the post-emergence activity of cyanazine and isoproturon

Table 5 shows that post-emergence application of cyanazine and isoproturon under dry soil conditions resulted in little phytotoxicity but on increasing the soil moisture content to close to field capacity, high activity was achieved. Under dry soil conditions adventitious roots failed to develop, but on wetting the soil surface rapid extension of these roots occurred (Table 6 and Photo 1).

Effect on herbicide performance of post-spraying rain

Following post-emergence spraying of cyanazine and isoproturon, application of 6 mm of simulated rain increased the activity of both herbicides when the pots were protected from natural rain. Herbicide treated plants that were kept outside after spraying were exposed to 36 mm of natural rain and herbicide activity was further increased particularly at lower doses (Table 3). With 6 mm of simulated rain cyanazine activity was greater under a warm compared to a cool, post-spraying regime (Figure 2).

While soil moisture and rainfall had major effects on herbicide activity against *B. sterilis*, relative humidity had little effect on the performance of cyanazine and isoproturon (Table 7).

Effect on herbicide activity of spraying the foliage only, the soil only, or both, with watering from above or below (Figure 4).

For cyanazine, isoproturon and SMY1500 most activity resulted from the soil drench with watering from above.

The next most effective treatment was the soil drench watered from below which was followed by the overall spray (foliage plus soil) with watering from above. The overall spray watered from below was moderately effective with SMY1500, but sub-lethal with cyanazine and particularly isoproturon. The foliage only treatment with watering from below was completely ineffective for all the herbicides.

Effect of adjuvants on herbicide activity

Agral and Silwet L-77 significantly increased the activity of post-emergence herbicide treatments under several temperature regimes without post-spraying rain (Tables 8 and 9). On plants with 5-6 leaves Agral improved performance more in combination with cyanazine than SMY1500 (Table 9). Tridiphane* improved the activity of cyanazine and metoxuron with a marginal beneficial effect on isoproturon (Table 8 and Figure 5). Codacide and Vinamul 18181* were generally ineffective. (Tables 8 and 9)

Agral, Silwet L-77 and tridiphane tended to increase damage to wheat cultivar Longbow (Table 10).

* tridiphane and Vinamul have been withdrawn by the manufacturers

DISCUSSION

Effect of growth stage on the control of sterile brome with herbicides

The growth stage of sterile brome at the time of spraying is an important factor in determining 'weather windows' for optimum herbicide performance. Early post-emergence treatments were the most phytotoxic. Beyond the 4-leaf growth stage, with the onset of tillering, sterile brome became less susceptible to all of the herbicides tested. Plants with 6 leaves and 3 tillers were not controlled by the recommended doses of chlorotoluron, isoproturon and metoxuron with regrowth from tillers making a major contribution to recovery. Cyanazine and SMY1500 controlled plants at this growth stage when post-spraying rain was applied. Peters (1991) reported that enforced dormancy may result in germination over a prolonged period. In these circumstances a single treatment is unlikely to provide satisfactory control and a sequence of herbicide treatments, such as pre-emergence tri-allate followed by cyanazine or isoproturon, may be required.

The effect of temperature on herbicide activity

At higher doses all of the herbicides were effective under cool simulated autumn/winter conditions (Table 2). Under warmer conditions 15/10°C (Table 3) or cool pre- followed by warm post-spraying conditions (Table 2 and Figure 2) herbicide activity was reduced except for cyanazine and SMY1500. Under warmer conditions herbicides tend to be metabolised more rapidly both in the plant and soil, but transpiration and therefore herbicide uptake from the soil is also increased when soil moisture is adequate. In these experiments water was not limiting and it is likely that increased metabolism was mainly responsible for the reduced phytotoxicity of chlorotoluron, isoproturon and metoxuron. The improved activity of all of the herbicide except SMY1500 (by tridiphane) supports this proposal (Table 8) as tridiphane synergises herbicide action by blocking degradation of some herbicides (Caseley 1992).

The improved activity of cyanazine by an increase in temperature and rainfall may result from rain moving the herbicide down the soil profile and the warmer temperature increasing transpiration (Figure 2).

Effect of soil moisture content on herbicide performance

Pre-emergence application of cyanazine and isoproturon to 'dry' compared to 'wet' soil surfaces reduced their activity but tri-allate performance was unaffected. In 'dry' soil, fewer of the binding sites on clay and organic matter are occupied by water. Consequently more herbicide is strongly bound and thus unavailable to the plant via the roots and underground parts of the shoot (Caseley & Walker 1989). Strong binding on the 'dry' soil also provides an explanation for the higher volume of post-spraying rain required to enhance herbicide performance. Cyanazine and isoproturon enter the plant in solution, whereas tri-allate has a high vapour pressure (16 mPa) and has phytotoxic activity via the vapour phase which is less affected by soil water content. It should be emphasised that in these studies only the top 1 cm of the soil profile was 'dry' and following sub-irrigation after herbicide application, the surface soil became moist within a few hours. Similar trends were seen in the field studies (Blair *et al.* 1994). In the pot and both field studies tri-allate performed well regardless of soil moisture and rainfall.

Post-emergence application of cyanazine and isoproturon to *B. sterilis* grown in dry soil (25% FC) resulted in little phytotoxicity if the soil remained dry, but satisfactory control if the soil moisture was increased to 100% FC (Table 5). In addition to the soil/herbicide interactions mentioned above, adventitious root development, close to the soil surface where the highest concentration of herbicide is located, is also affected by soil moisture. At 25% FC no adventitious roots are present but on increasing the soil moisture to 100% rapid root extension occurs facilitating herbicide uptake (Table 6 and Photo 1).

The effect of post-spraying rain on post-emergence herbicide activity

The herbicides used in this project, apart from tri-allate, are inhibitors of photosynthesis which are transported in the xylem. Thus herbicides penetrating the leaf move in the transpiration stream towards the margins and tip of the leaf, while herbicides entering the roots and underground parts of the shoot are systemic and reach the whole shoot including developing leaves and tillers. The beneficial effects of rain on these herbicides result from:

1) deposition of herbicide on the soil from the foliage and its transport down the soil profile where it may come into contact with the underground parts of the shoot and roots. Wetting the soil surface also promotes the development of adventitious roots (see above).

2) redistribution of active ingredient on the plant surface with deposits washed into leaf sheaths entering leaves and sometimes tillers (Caseley 1991).

Effect on herbicide activity of spraying foliage only, soil only or both.

This experiment demonstrated that cyanazine and isoproturon, and to a lesser extent SMY1500, deposited on the foliage had very little phytotoxic effect. When herbicide is sprayed on the foliage and soil, watering from above is required to move the herbicides down the soil profile into the root zone. The soil drench treatment, applied in 10 ml of water per pot, distributed the herbicides in the root zone and was the most phytotoxic treatment.

Effect of adjuvants on herbicide performance

Agral and Silwet L-77 improve herbicide activity by enhancing herbicide retention and uptake by the foliage. West and Clay (1988) found that several surfactants increased foliar uptake of herbicides used to control some grasses and accelerated desiccation, but regrowth from tillers often occurred when the soil was protected from herbicide deposition. When surfactant plus herbicide was applied overall, to foliage and soil, activity was enhanced compared to herbicide alone. These authors suggested that the surfactants increased the soil activity of the herbicides. In our experiments no post-spraying rain was applied, but the higher doses of herbicide plus adjuvant killed the brome (Figure 3 and Table 8), suggesting soil activity was increased.

These results clearly demonstrate that herbicide activity against brome may be improved with surfactants, but Table 10 suggests that crop damage will also be increased.

CONCLUSIONS

- Brome is most susceptible to chlorotoluron, cyanazine, and metoxuron at early growth stages (2 leaves) and plants with six or more leaves are unlikely to be controlled.
- Application of herbicides to moist compared to dry soil results in better brome control following both pre- and post-emergence treatments.
- Rain after application moves the herbicide into the root zone which is essential for high herbicide activity. If dry soil has been sprayed large amounts of rain will be required to make the herbicide available to the brome.
- Tri-allate is more effective than other brome herbicides for pre-emergence application to dry soil.
- Surfactants such as Agral and Silwet L-77 increase the activity against brome of chlorotoluron, cyanazine, isoproturon and metoxuron, but the risk of crop damage is increased.
- Chlorotoluron, isoproturon and metoxuron are most effective at cooler temperatures while cyanazine is equally active when conditions become warmer, for example in the spring.
- Due to seed dormancy brome may emerge over an extended period and a sequence of applications may be required e.g. pre-emergence use of tri-allate, particularly under dry soil conditions, followed by isoproturon, chlorotoluron, cyanazine or metoxuron.
- frost and relative humidity have relatively little effect on herbicide performance.

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Table 1. **Effect of growth stage of *B. sterilis* on the activity of 5 herbicides under controlled environment simulated autumn/winter conditions (% of control)**

Sprayed at: 2 leaf growth stage

	% of recommended field dose			
herbicide	20	40	60	80
chlorotoluron	-	77.4	74.5	31.9
cyanazine	64.1	72.1	54.0	13.0
isoproturon	81.2	63.8	47.5	23.0
metoxuron	-	63.4	50.9	18.9
SMY 1500	46.2	21.0	12.4	3.3

LSD ($p < 0.05$) 13.94

Fresh weight of untreated control 7.40 g

Sprayed at: 4 leaf growth stage

	20	40	60	80
chlorotoluron	73.2	63.1	57.1	37.7
cyanazine	96.6	81.8	59.1	28.8
isoproturon	107.3	68.5	35.4	24.0
metoxuron	80.1	82.4	42.3	41.2
SMY 1500	49.2	36.6	34.5	20.7

LSD ($p < 0.05$) 12.65

Fresh weight of untreated control 5.94 g

Sprayed at: 6 leaf 1-2 tiller growth stage

	40	60	80	100
chlorotoluron	76.2	75.0	78.8	73.0
cyanazine	76.3	70.1	50.6	24.1
isoproturon	95.1	68.5	69.1	61.2
metoxuron	90.9	89.3	74.6	58.1
SMY 1500	63.6	47.3	36.2	17.7

LSD ($p < 0.05$) 14.80

Fresh weight of untreated control 7.43 g

Table 2. **Effect of temperature on the activity of five herbicides against *Bromus sterilis* with 2-3 leaves - cool conditions compared with cool pre- and warm post-spraying conditions (% of control fresh weight)**

herbicide	% of recommended field dose			
	20	40	60	80
chlorotoluron		77.4	74.5	31.9
cyanazine	64.1	72.1	54.0	13.0
isoproturon	81.2	63.8	47.5	23.0
metoxuron		63.4	50.9	18.0
SMY1500	46.2	21.0	12.4	3.3

fresh weight of untreated control 7.40 g LSD ($p < 0.05$) 13.94

	20	40	60	80
chlorotoluron		86.6	85.7	78.4
cyanazine	83.3	58.6	28.8	10.6
isoproturon	100.9	88.6	69.2	55.8
metoxuron		99.0	71.7	49.3
SMY1500	15.2	8.2	4.7	2.5

fresh weight of untreated control 8.01 g LSD ($p < 0.05$) 17.02

Table 3. **Effect of two temperature and three rain regimes on the activity of cyanazine and isoproturon on *B. sterilis* (% of untreated control fresh weight)**

Herbicide % of recommended dose	Rain 6 mm	glasshouse 15/10	plastic rain cover 8/3	outside (+36 mm of rain) 8/3 °C*
Cyanazine				
20	-	104.8	94.8	103.3
	+	110.2	95.8	98.8
40	-	67.9	71.1	41.3
	+	26.8	50.7	29.5
60	-	38.7	44.2	8.8
	+	14.1	22.4	5.1
80	-	13.7	35.3	0.4
	+	8.5	12.4	0.1
100	-	15.5	33.0	0.1
	+	0.3	5.4	0.1
Isoproturon				
20	-	94.8	89.7	90.1
	+	100.8	82.4	63.5
40	-	108.5	66.4	38.9
	+	86.9	31.0	20.5
60	-	63.2	25.5	9.3
	+	50.0	4.1	20.3
80	-	38.7	13.0	0.8
	+	4.8	0.9	5.5
100	-	17.5	20.4	0.9
	+	2.3	0.1	0.2

LSD ($p < 0.05$) 27.74

Weight of untreated controls	6.53 g	3.20 g	2.94 g

Sprayed at 2-3 leaf growth stage

Assessed at 6 leaf growth stage

* average temperature °C day/night respectively

Table 4. **Effect of frost immediately before or after spraying on the activity of five herbicide against *B. sterilis* with 2-3 leaves (% of control fresh weight)**

frost[a] / herbicides[b]	none	before spraying	after spraying
chlorotoluron	74.1	52.7	68.8
cyanazine	67.0	64.3	62.5
isoproturon	42.0	50.9	45.5
metoxuron	56.3	44.6	63.4
SMY1500	28.6	25.0	17.9
		LSD ($P < 0.05$)	14.4

untreated control fresh weight = 1.29g

[a] mean of frost treatments of -2 and -6°C for 8 h at night immediately before and after spraying

[b] mean of 20, 40, 60 and 80% of recommended herbicide dose

Table 5. **Effect of soil water deficit on the activity of cyanazine and isoproturon against *B. sterilis* sprayed at the 2-3 leaf growth stage (% of untreated control)**

A. Soil moisture 25% FC before and after spraying

	% of recommended dose			
herbicide	40	60	80	100
cyanazine	98.4	106.9	85.9	65.5
isoproturon	110.8	90.7	92.3	78.1

untreated control fresh weight 5.24 g LSD ($p < 0.05$) 18.74

B. Soil moisture 25% FC before and 100% after spraying

cyanazine	38.2	20.8	4.8	0.6
isoproturon	72.4	47.6	0.9	0.1

untreated control fresh weight 7.01 g LSD ($p < 0.05$) 22.43

The plants were grown throughout in a controlled environment at 16/10°C.

Water was dispensed by syringe to weighed pots via a tube for 25% FC and to the soil surface to maintain 100% FC.

25% FC soil contained 8.25 g water per 100 g of dry soil.

Table 6. **Length and weight of adventitious roots of *B. sterilis* following increasing field capacity (FC) from 25 to 100%**

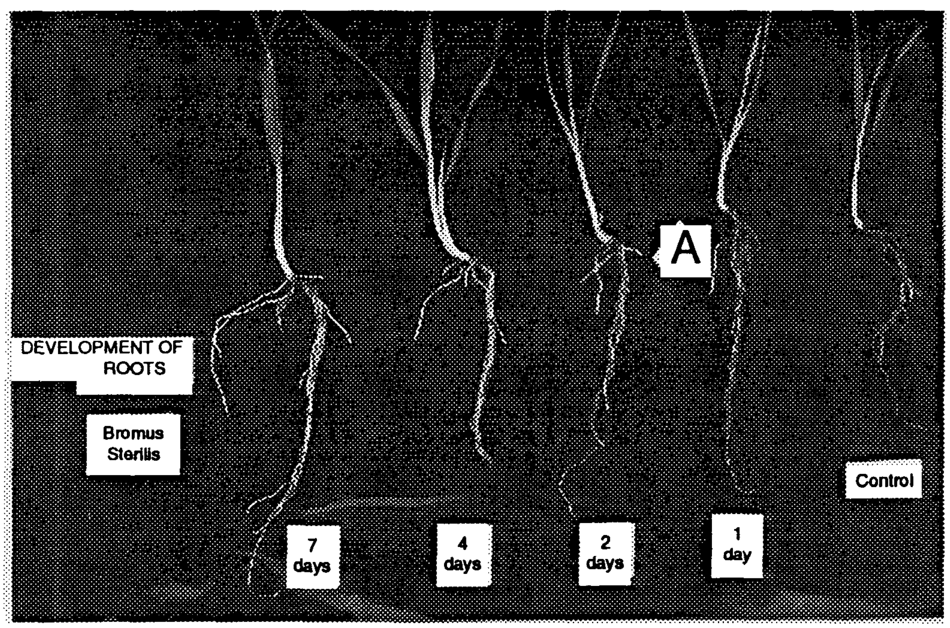
	Days at 100% FC					
	0	1	2	4	7	10
length (mm)	3.0	8.5	36.0	84.3	196.2	280.3
weight[a]	1	1	5	9	21	26

[a] (adventitious as % of total roots)

Plants were grown at 25% FC (sub-irrigation by tube) until the 2-3 leaf growth stage when FC was increased to 100% by watering the soil surface.

Soil at 25% FC contains 8.25 g water per 100 g of soil.

Photo 1. **The effect of increasing soil moisture content on the growth of adventitious roots of *B. sterilis*.**



A Adventitious roots

days refer to time after increasing the soil moisture from 25% FC to 100% FC

control maintained at 25% FC

Table 7. **Effect of relative humidity (RH) on the activity of cyanazine and isoproturon against *Bromus sterilis* (fresh weight of shoots as percent of untreated control)**

Herbicide	% of recommended dose	% RH 25/40	75/86	85/93
cyanazine	20	100.46	87.58	94.17
	40	56.32	61.14	57.92
	60	37.49	28.24	34.22
	80	7.36	20.71	5.22
	100	11.04	2.22	10.53
	mean	42.53	39.98	37.37
isoproturon	20	86.75	104.38	98.46
	40	78.42	67.14	84.92
	60	56.32	39.76	43.49
	80	21.54	20.53	28.44
	100	13.09	5.26	11.04
	mean	51.22	47.41	53.27

LSD ($p < 0.05$) 24.52 for individual doses
15.74 for mean of doses

untreated control fresh weight 8.42 g

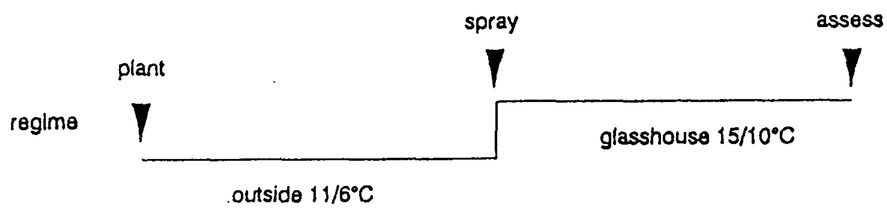
The plants were grown in controlled environment rooms at 16/10 ± 1°C and sprayed at the 3-4 leaf growth stage. Rain (6 mm) was applied one week after spraying.

Table 8. **Effect of three adjuvants on the activity of five herbicides applied to *B. sterilis* at the 2-3 leaf stage under three environmental regimes (% of untreated control fresh weight)**

	Adjuvant			
Herbicide*	None	Silwet L-77	Vin 18181	Tridiphane
chlorotoluron	55.0	35.4	93.0	36.0
cyanazine	64.1	34.2	87.3	49.3
isoproturon	56.2	31.5	75.2	46.2
metoxuron	58.8	40.4	103.0	53.3
SMY1500	25.3	17.9	50.8	45.1

LSD ($p < 0.05$) 11.68

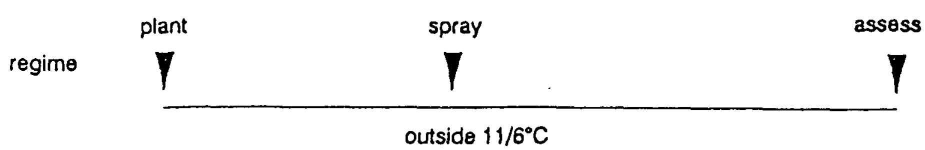
fresh weight of untreated control 7.40 g



chlorotoluron	42.6	18.5	47.0	37.3
cyanazine	41.3	16.5	41.7	13.7
isoproturon	42.8	30.9	28.4	35.9
metoxuron	34.4	17.5	33.9	21.6
SMY1500	35.8	21.8	22.4	50.6

LSD ($p < 0.05$) 9.83

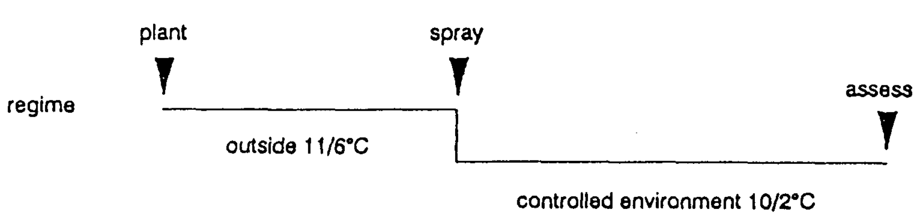
fresh weight of untreated control 3.61 g



chlorotoluron	76.3	67.3	82.9	78.3
cyanazine	84.0	56.8	75.1	44.4
isoproturon	91.6	91.9	94.5	61.2
metoxuron	77.3	74.7	90.4	77.5
SMY1500	58.8	24.4	41.0	43.2

LSD ($p < 0.05$) 16.06

fresh weight of untreated control 12.96 g



* Herbicides: mean of 20, 40, 60 and 80% of the recommended dose

Table 9. **Effect of Agral and Codacide (1:1) on the activity of cyanazine and SMY1500 against *B. sterilis* plants with 5-6 leaves at time of spraying (% of untreated control)**

	Herbicide	% of recommended dose				
		0	10	20	40	80
Additive						
None	Cyanazine	98.4	86.0	96.7	82.7	26.6
Codacide	"	96.3	94.2	86.9	83.3	9.4
Agral 0.5%	"	97.5	87.4	81.4	17.4	12.3
None	SMY1500	98.4	98.7	72.7	46.7	21.8
Codacide	"	96.3	102.3	81.4	59.6	39.3
Agral 0.5%	"	97.5	94.3	77.8	54.5	10.7

LSD ($p < 0.05$) 21.2

Fresh weight of untreated control 14.66 g

Agral 0.5% W/V
Codacide 1:1 volume of formulated herbicide concentrate.

The plants were grown at 13/9°C, subirrigated, but not subjected to post spraying rain.

Table 10. **Effect of cyanazine and isoproturon with and without adjuvants on wheat cv Longbow (% of untreated control fresh weight)**

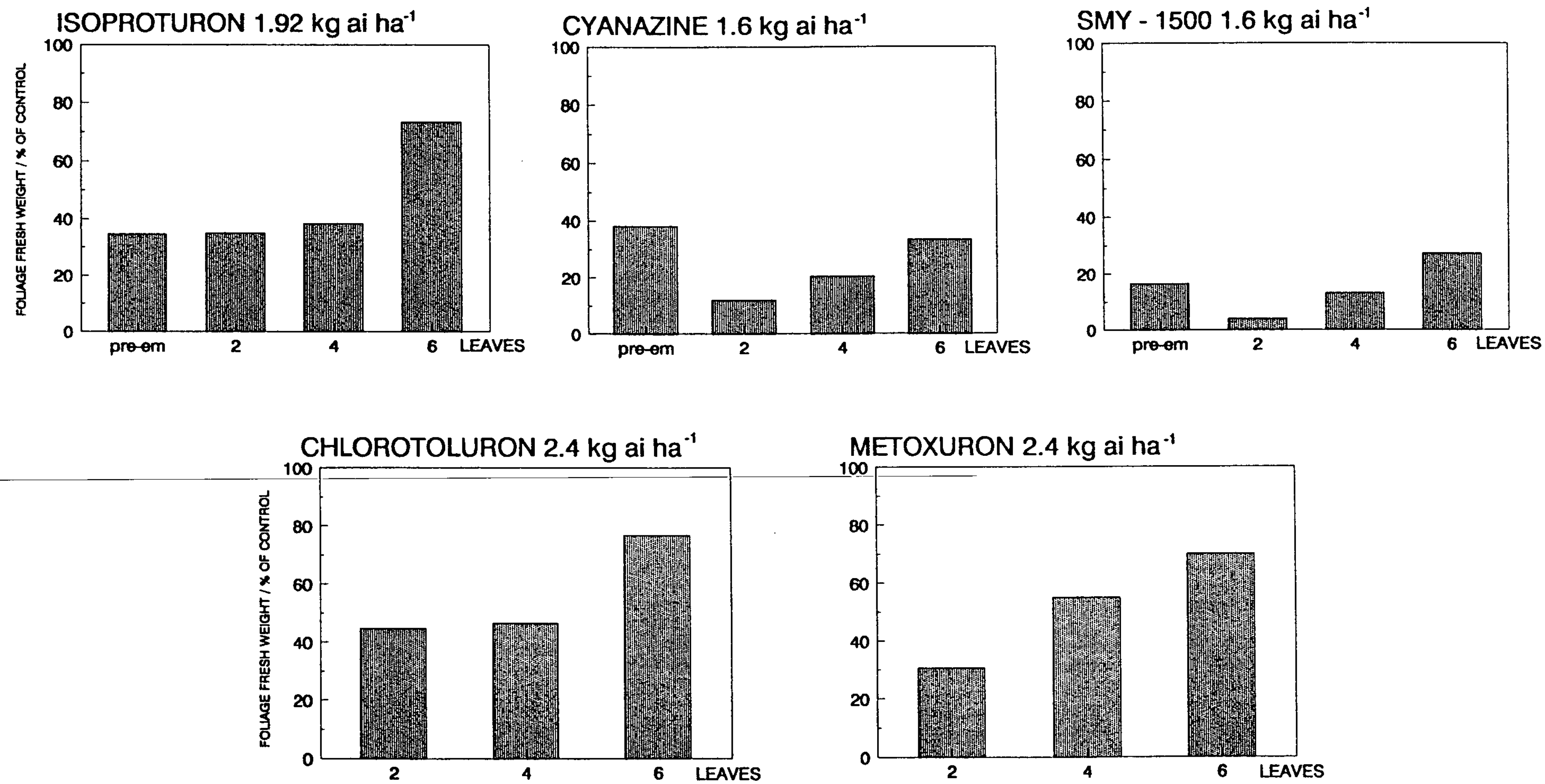
Additive	Herbicide	% of recommended dose 20	40	80
None	Cyanazine	98.4	88.7	62.9
Agral 0.5%		73.6	60.5	46.2
Silwet L-77 0.1%		80.4	58.5	52.8
Tridiphane (125 g ai ha^{-1})		88.9	81.4	42.7
None	Isoproturon	100.4	108.3	96.8
Agral 0.5%		88.3	60.1	57.4
Silwet L-77 0.1%		98.1	80.2	78.7
Tridiphane (125 g ai ha^{-1})		90.5	92.9	86.3

LSD ($p < 0.05$) 16.32

untreated control fresh weight 5.62 g

sprayed at 2-3 leaf growth stage and grown at 16/10°C

Figure 1 Effect of growth stage on susceptibility of B. sterilis to five herbicides applied at 80% of recommended dose



Each column represents the average foliage fresh weight of plants from two pre- and nine post-spraying regimes.

Figure 2 **The interaction of temperature and rain on cyanazine activity against *B. sterilis* - rain has less effect under a constant cool environment A compared to a warm environment B**

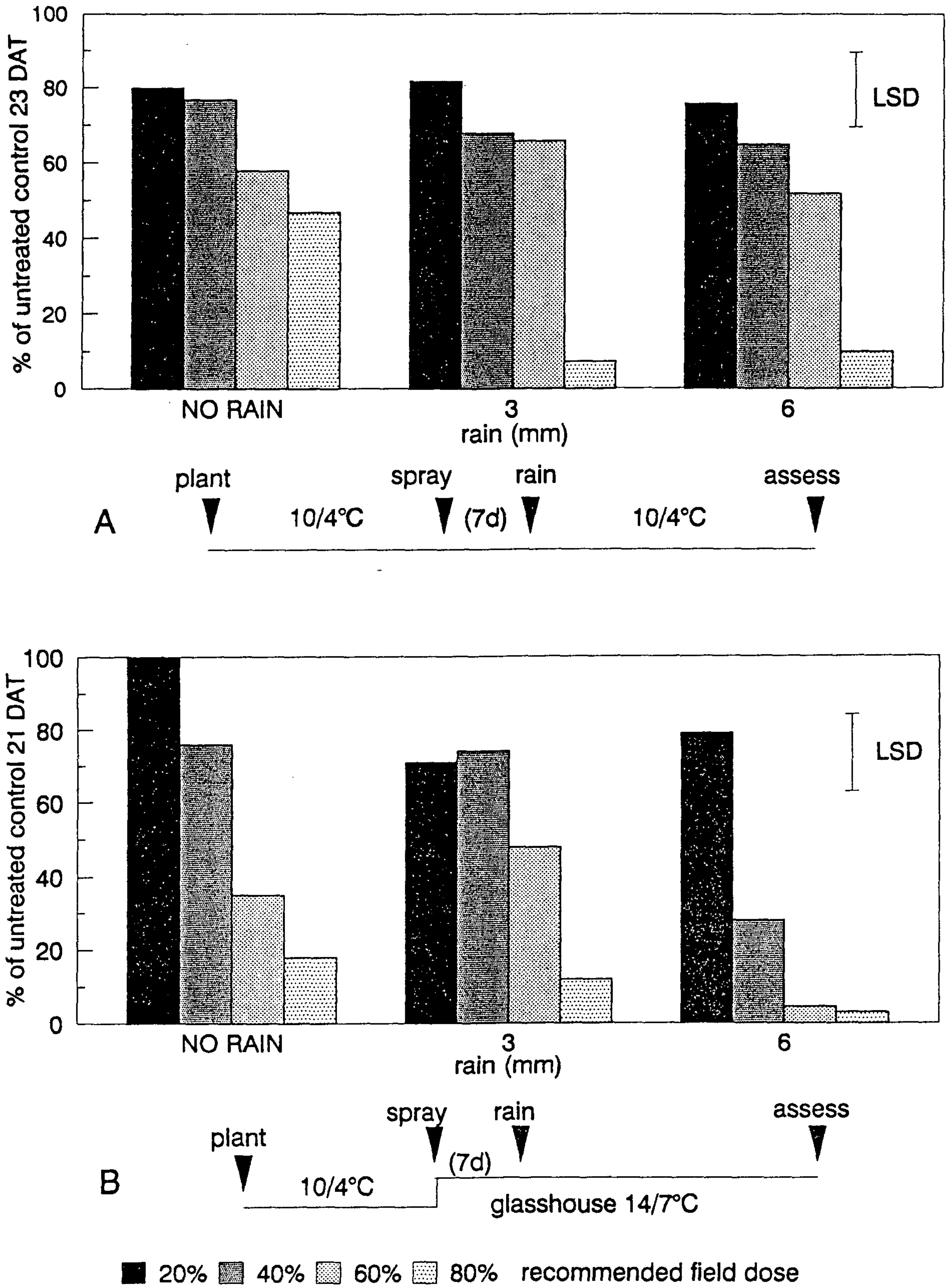


Figure 3 **Effect of soil moisture content at time of spraying and post-spraying rain on the pre-emergence activity of cyanazine, isoproturon and tri-allate (% of control of foliage fresh weight)**

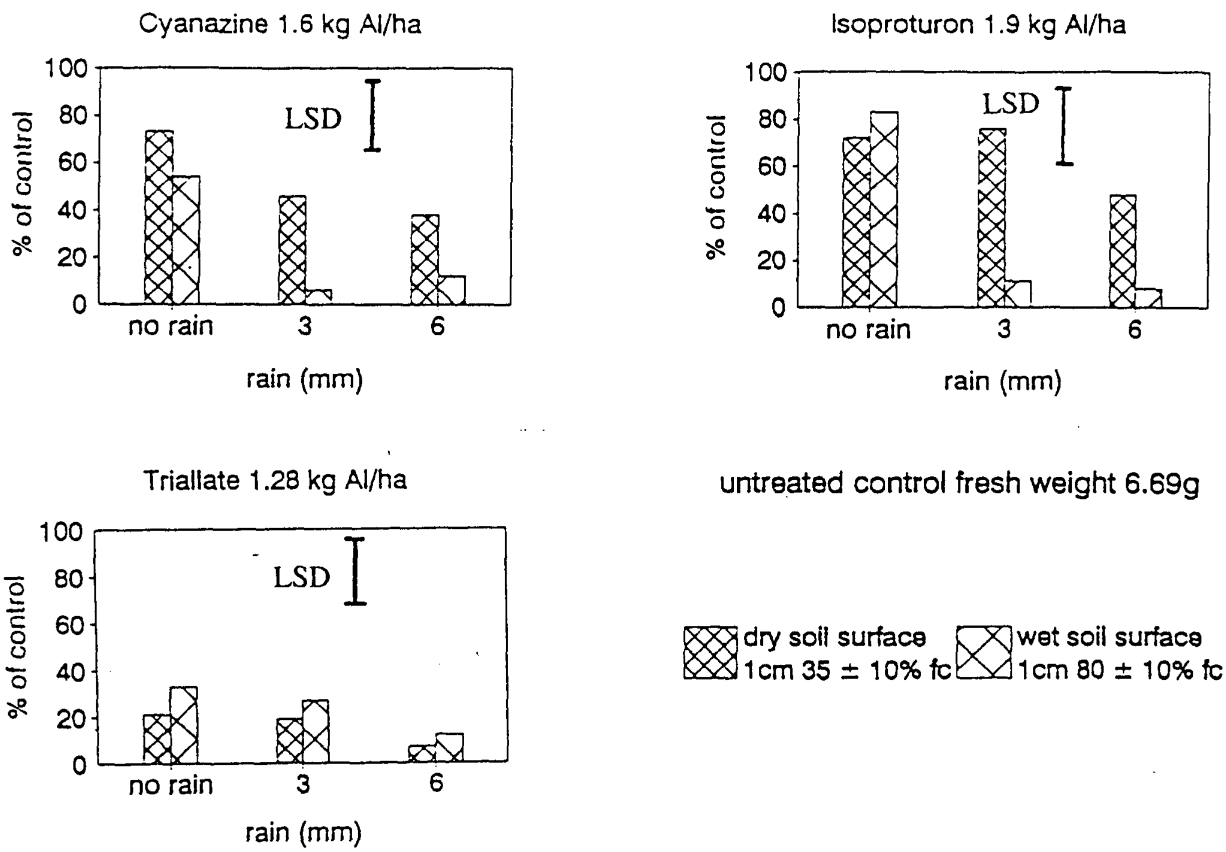
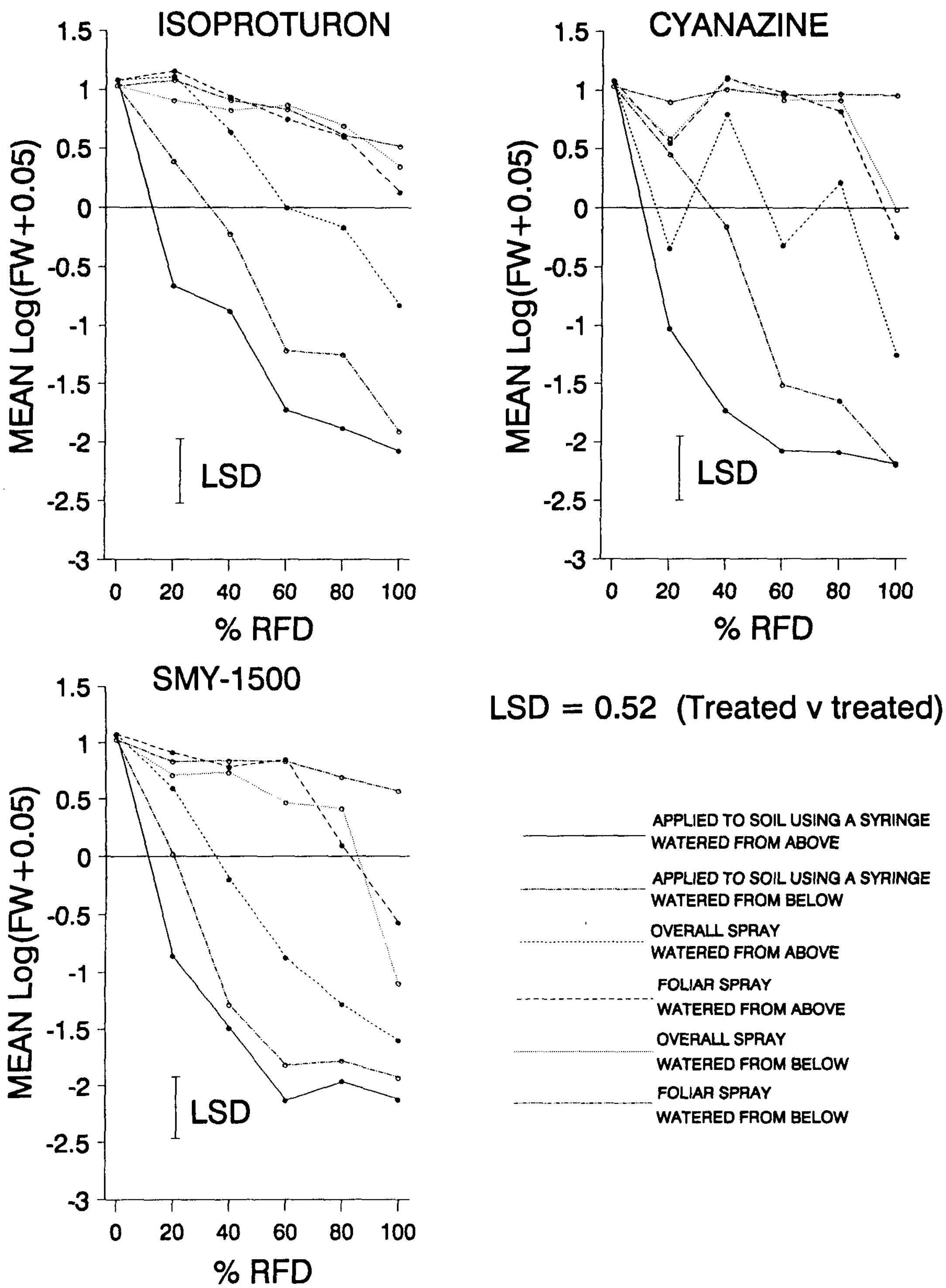


Figure 4 **Effect on herbicide activity of spraying the foliage only, the soil only or both with watering from above or below**

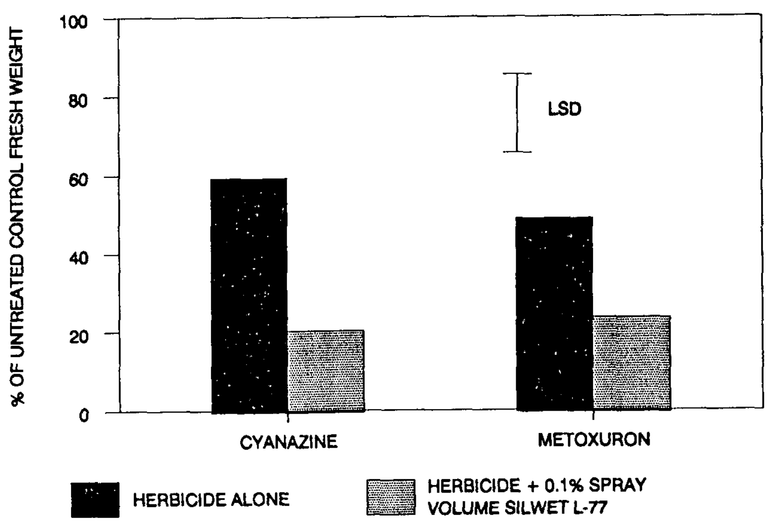


The fresh weight of untreated control plants was 6.85g.

To facilitate statistical analysis a log shoot weight ± 0.05 transformation was used.

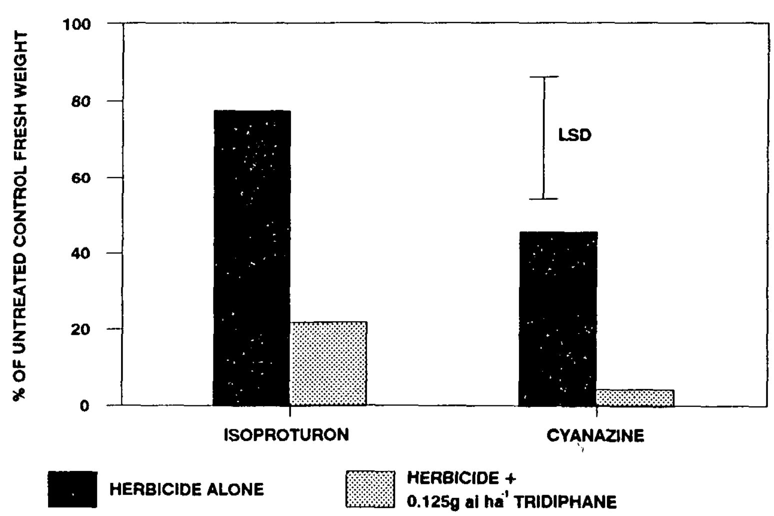
Figure 5 Effects of Silwet L-77 (surfactant) and tridiphane (synergist) on herbicide activity against <u>B. sterilis</u>

A. Effect of Silwet L-77 on cyanazine and metoxuron activity



Herbicides applied at 40% of recommended field dose to plants with 2-3 leaves grown throughout at 10/5°C without rain. Fresh weight of untreated controls 6.14g.

B. Effect of tridiphane on cyanazine and isoproturon activity



Herbicide applied at 80% of the recommended field dose to plants with 2-3 leaves grown at 16/10°C without rain. Fresh weight of untreated controls 11.84g.